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RUNOFF AND SEDIMENT PRODUCTION AFTER SITE PREPARATION BURNING

by

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SUMMARY:
Post harvest slash burning is a common site preparation technique used throughout the southeastern United States. Little qualitative information exists on the hydrologic response to various burn severities. This study was conducted to compare the effects of two burn severities on runoff and sediment production during a rainfall simulation experiment in the Southern Appalachian mountains. Sediment yields increased 40 fold between low- and high-severity burn plots.

KEYWORDS:

erosion, runoff, sediment, timber harvest, burning

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RUNOFF AND SEDIMENT PRODUCTION AFTER SITE PREPARATION BURNING

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INTRODUCTION

Foresters, hydrologists, and soil scientists have long been concerned with fire effects on soil (Arend 1941, Wells et al., 1979), particularly with erosion following fires on steep terrain (Van Lear and Kapeluck, 1989). Sediment production after fires, whether prescribed or wildfire, is a serious problem nationwide. Little qualitative information is available on the hydrologic and sedimentation effects of various burn severities in timber harvest areas. The USDA-Forest Service, Intermountain Research Station is developing physical process models for use in estimating onsite runoff and sediment production from timber harvest areas and forest roads (Burroughs et al. 1991). This effort is in conjunction with USDA-Agricultural Research Service Water Erosion Prediction Project (WEPP). The development, verification and validation of such models depends on availability of plot runoff and sediment data under various management conditions.

Post-timber harvest slash burning is the most common site preparation treatment used nationwide, singly and in combination with other treatments, to dispose of slash, reduce the risk of insects and fire hazards, prepare seedbeds, and suppress plant competition prior to planting timber species. In the Southern Appalachians and Piedmont regions of the Southeast, site preparation burning is commonly used to convert low-quality hardwood stands to pine-hardwood mixtures (Phillips and Abercrombie, 1987).

Several types of burning are commonly employed: brown-and-burn techniques which use herbicides to control vegetation then ignite residuals; fell-and-burn techniques which use dry leaved-out slash to carry the fire; and late summer/fall burns which use dying residual vegetation to carry the fire. The most important factor affecting soil response to burning is fire severity, i.e., the condition of the forest floor after burning (Wells et al., 1979). Severe burns consume all organic matter and expose mineral soil. The depth of the organic layers (forest floor, humus layer, root mat) above mineral soil must be considered prior to burning. Burns of similar intensity and residence time will have greater impact on sites where the organic layer was thin before burning.

Water and sediment yields may be increased by burning. The amount of increase depends on the severity of burning and the portion of the area burned. When vegetation is consumed, interception and evapotranspiration are reduced. Where the organic layers of the forest floor are consumed and mineral soil exposed, infiltration and water storage capacities

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are reduced. The impact of fire effects range from very short periods (weeks) to decades depending on the severity and intensity of the fire, and the rate of vegetative recovery, which is influenced by both natural conditions and remedial measures applied by man (Baker, 1990).

Studies on the effects of burning on erosion in the South are limited and results are conflicting (Douglass and Van Lear, 1983). Van Lear and Danielovich (1988) reported erosion rates of 1.59 t/ha/yr in the Southern Appalachian Mountains after a high-intensity prescribed burn on slopes ranging from 21 to 43%. Shahlaee et al. (1991) reported erosion rates of 0.95 t/ha for an 8-month period on a 30% slope in the upper Piedmont under natural rainfall after a low severity burn. Another study in the upper Piedmont was conducted with simulated rainfall to examine the effects of burning on each layer of the forest floor (Robichaud and Shahlaee, 1991). Low severity burning increased sediment production elevenfold compared to unburned control plots. Ralston and Hatchell (1971) reported that soil losses were 7.4 t/ha/yr in a North Carolina burn study. These reported differences are likely due to various methods of assessing erosion and runoff; and variation in rainfall intensities, slope, conditions of the ground surface and plots verses watershed studies. Additional qualitative information is needed to develop physical-based model parameters to predict effects of various site preparation burns on runoff and sediment production.

The objective of this research was to compare the effects of low- and high- severity fires, when using the fell-and-burn site preparation technique, on runoff and sediment production under simulated rainfall.

METHODS AND SITE DESCRIPTION

The study was conducted in the Andrew-Pickens Ranger District of the Sumter National Forest, in northwest South Carolina during the summer of 1991. This location had a mixed pine-hardwood forest on varying slopes up to 65% in the Southern Appalachian foothills. The region is transitional between the central deciduous forest and the prevailing pine forest in the Southeast. The study site was bisected by a road/fire break that made it suitable for conducting two burn severities in the same stand. Slopes within the study area ranged from 23% to 39% with a southern aspect. The predominant soil type is the Cowee Series, a fine-loamy, oxidic, mesic Typic Hapludult formed in residuum, from weathered granite, gneiss, and schists.

Timber was commercially harvested on 14 ha during the winter of 1990/91 leaving the undesirable stems standing. The stand consisted of 60% hardwood and 40% pine with an average basal area of 20.9 m^2/ha. Major overstory hardwood species included: scarlet (*Quercus coccinea* Muench.), northern red (*Q. falcata* Michx.), black (*Q. velutina* Lam.), and white (*Q. alba* L.), chestnut (*Q. prinus* L.) and post oaks (*Q. stellata* Wangenh.). Shortleaf pine (*Pinus echinata* Mill.) was the predominate overstory pine species. Understory and midstory hardwoods included red maple (*Acer rubrum* L.), blackgum (*Nyssa syvatica* Marsh.), sourwood (*Oxydendron arboreum* L.), persimmon (*Diopyros virginiana* L.), and black cherry (*Prunus serotina* Ehrh.). Standing residual stems greater than 1.5 m tall were chain-saw felled in May for the low-severity treatment and mid-June for the high-severity treatment.

Prior to and following burning, fuel loading and duff thickness were determined by the line transect estimation method (Brown, 1974). Differences in fuel load surveys were used to determine total fuel consumption and duff reduction. Fifteen semi-permanent plots were established in a systematic grid in each burn area. Randomly selected, 15 m transect lines were directed radially from each plot center for woody fuel measurements. Duff pins were installed flush with the forest floor surface and measured after the fire to determine total litter depth and litter consumption. Sufficient time was allowed after the burn for the ash to be dispersed or settled before post-burn measurements were made.

Heat penetration into the soil profile was measured with thermocouples placed 10 mm above the forest floor-mineral soil interface, at the forest floor-mineral soil interface, and 10 mm into the mineral soil. Ten locations for each burn treatment were used to record temperatures during the fire. Thermocouple measurements were recorded at 15 sec intervals on a data logger buried nearby.

Burning prescriptions were selected which would produce conditions of low- and high-severity. The low-severity burn was conducted on June 5, which was six days after a rainfall that totaled 37 mm over a 4-day period. The high-severity burn was conducted on July 15, 12 days after a rainfall of 44 mm. Other fuel and weather measurements are presented in table 1 for both fires. The major differences between burning dates was the moisture content of the forest floor layers (litter and duff). For the low-severity burn, litter moisture was 65% and duff moisture was 98%, while these measurements for the high-severity burn were 6% and 37%, respectively. Both fires were ignited using strip headfire technique with strips approximately 20 m apart.

Table 1. Fuel and weather conditions at the time of ignition for the low- and high-severity burns.

Measurements	Low Severity	High Severity
Relative humidity	48%	55%
Wind speed	5 - 11 kph	8 - 11 kph
Wind direction	SE	SE
Ambient temperature	18°C	30°C
Woody fuel moisture (6-26 mm)	17.7%	6.3%
Litter moisture	65.2%	5.9%
Duff moisture	98.2%	36.9%
Soil moisture	35.7%	24.5%

After each burn, four erosion sites were located randomly in each treatment areas (eight total), excluding skid trails and landings for the simulated rainfall experiments. Each site consisted of three plots: one 3 m wide by 7.5 m (22.5 m^2) plot; two 0.5 wide by 1 m (0.5 m^2) plots adjacent to each 22.5 m^2 plot. Plots were delineated by 150 mm sheet metal placed vertically 50 mm into the ground.

A simulated rainfall event was applied to each site with a USDA-Forest Service modified Purdue type (oscillating nozzle) rainfall simulator with an average rainfall intensity of 100 mm/hr. This was determined by 12 raingauges located within and around the perimeter of the 22.5 m^2 plots. Three 30-minute rainfall applications, of approximately 100 mm/hr intensity, were applied to the plots. Run 1 (dry run) was conducted with the existing soil moisture condition. After run 1, the plots were covered with plastic tarps, and run 2 (wet run) was performed the following day. Run 3 (very wet run) was conducted about 30 minutes after run 2.

A covered trough at the lower end of each plot conducted water and sediment through an outlet tube for timed volume samples. Timed runoff samples were collected manually in 1000 ml bottles. At the end of each run, any remaining residual sediment was washed from the collection trough into bottles. All samples were weighed and oven dried to determine runoff rates and sediment concentrations. Runoff rates were converted to millimeters of runoff and sediment production units were kilograms per hectare per millimeter of runoff. The latter value is equivalent to concentrations in milligram per liter divided by 100 and are used to remove the effects of different runoff volumes (Foltz and Burroughs, 1990). The two 0.5-m^2 plots were used to compare effects of removing the remaining forest floor (exposing bare soil) on runoff and sediment production.

RESULTS AND DISCUSSION

The two burning prescriptions created fires of widely differing behavior, resulting in conditions of low- and high-severity. The high-severity treatment produced a fire that was hotter and faster than the low-severity fire (table 2). Flame lengths in the high-severity burn were approximately twice those of the low-severity burn (6 vs 3 m) while the rate of spread was 12 times greater (18 vs 1.5 m/min). After burning, the forest floor on the low-severity site had a blackened appearance while the high-severity site was mostly brown with white ash where logs had been consumed. A blackened appearance indicates that the forest floor was charred but not entirely consumed (low severity) and the brown coloring is due to the exposure of mineral soil, indicating a severe burn (Phillips and Abercrombie 1987). On the low-severity site, a portion of the litter layer was not consumed and the majority of the duff layer remained intact (table 2). On the high severity site, the litter layer was entirely consumed at almost all sample points and the duff layer was consumed at 47% of the sample points averaging only 10 mm thick where it was present.

Table 2. Selected fire behavior parameters and fuel consumption characteristics for low- and high-severity burns.

Measurement	Low Severity	High Severity
Firing technique	strip headfire	strip headfire
Fuel moisture sticks	11%	8%
Flame height	1 - 3 m	2 - 6 m
Fireline intensity	215 - 2945 kw/m	655 - 13,295 kw/m
Max. 10-min average temperature		
@ mineral soil surface	118°C	436°C
@ 10 mm below interface	50°C	281°C
Preburn litter depth	37 mm	29 mm
Postburn litter depth	10 mm	1 mm
Preburn duff depth	76 mm	42 mm
Postburn duff depth	53 mm	10 mm
Woody fuels (0-6 mm)		
Preburn	0.87 t/ha	0.48 t/ha
Postburn	0.17 t/ha	0 t/ha
Woody fuels (7-25 mm)		
Preburn	5.67 t/ha	2.24 t/ha
Postburn	2.76 t/ha	0.82 t/ha

Thermocouple measurements confirmed the relative difference in fire severity. The low-severity fire had relatively low temperatures with a maximum of 175°C at the mineral surface-duff interface and 70°C at 10 mm into the mineral soil (table 2). The high severity fire had several readings over 450°C at the mineral surface-duff interface and 400°C at 10 mm into the mineral soil.

Runoff rates, total sediment and adjusted sediment yields for the large plots (22.5 m^2) are presented in table 3. Average runoff rates increased by 10-fold and total sediment increased 50-fold between the two burn severities. The slopes for each plot varied from 23 to 39%. A slope adjustment factor (McCool et al. 1987) was used to convert sediment yield values to a uniform slope of 30%. Average sediment yields (kg/ha) increased 40 times between the low- and high-severity plots after adjustment. If you compare sediment yields after normalizing for runoff (kg/ha-mm) there is only twice as much between treatments which indicates the increase is from increased runoff and not changes in soil erodibility. Variability was high between plots due to differences in infiltration rates which correspond to varying runoff rates; this can also be seen by comparing the runoff/rainfall ratios. These differences are due to varying conditions of the forest floor after the burn. The burn is not uniform over the entire area and there is physical variability in soil and forest floor characteristics on forested hillslopes. Because of these variations, extrapolation of this data to a hillslope or small watershed is inappropriate.

Table 3. Summary of runoff and sediment yields for the eight large plots (22.5 m^2). Three runs averaged.

Severity and Plot		Runoff (mm)	Total Sediment (g)	Runoff/ Rainfall Ratio	Slope (%)	Adjusted Sediment Yields (kg/ha)	(kg/ha/mm)
Low	1	0.3	25.0	0.01	27	12.2	41.5
	2	0.4	37.7	0.01	24	21.6	65.1
	3	0.4	16.8	0.01	25	9.2	25.5
	4	0.8	28.8	0.02	33	11.6	11.6
Average		0.5	27.1			13.6	35.9
High	1	12.8	3460.2	0.28	33	1386.7	108.5
	2	1.4	263.9	0.03	39	89.4	65.6
	3	0.5	27.2	0.01	34	10.7	24.6
	4	7.4	1744.8	0.14	30	763.7	102.1
Average		5.5	1374.0			562.6	75.2

Table 4. Effects of rainfall events on runoff, total sediment and sediment yield from the eight large plots (22.5 m^2).

Run (Rain Appl.)	Runoff (mm)	Total Sediment (g)	Adjusted Sediment Yields (kg/ha-mm)
Dry	2.9 a*	944.4 a	77.3 a
Wet	2.9 a	587.5 a b	49.7 b
Very Wet	2.6 a	424.1 b	42.0 b

*-means with the same letter are not significantly different at 0.05 level of probability.

If we look at all the plots together and compare effects of each rainfall event, each event significantly reduced total sediment and sediment yield (table 4). One would expect a continuous reduction of sediment with subsequent rainfall as long as the integrity of the remaining forest floor is left intact.

The 0.5-m^2 plots were used to examine the effects of total removal of the remaining forest floor exposing bare mineral soil and existing conditions after the fire (table 5). Runoff rates increased 4 fold on the low-severity plots and were about the same on the high-severity plots. Total sediment increased 35-fold on the low-severity plot and doubled on the high-severity plots. Adjusted sediment yields showed a 37-fold increase on the low-severity plots and only a 2.5 fold increase on the high-severity plots. Thus, the smaller differences between the high-severity plots indicate how close to a bare soil condition, the high-severity fire was. This suggests that any additional disturbances to the forest floor such as skid trails and landings could greatly increase the overall effect of on-site sediment production.

Table 5. Summary of runoff and sediment values for the 14 small plots (0.5 m^2).

	Severity and Plot	Runoff (mm)	Total Sediment (g)	Runoff/ Rainfall Ratio	Slope (%)	Adjusted Sediment Yields (kg/ha)	(kg/ha/mm)
	Low						
1	No plots						
2	Existing	0.9	3.8	0.02	24	97.6	119.9
	Bare soil	13.2	210.4	0.30	24	5417.2	372.5
3	Existing	6.7	5.0	0.14	25	122.8	17.5
	Bare soil	23.7	201.9	0.50	25	4984.5	253.8
4	Existing	5.1	6.7	0.11	33	119.9	22.9
	Bare soil	12.7	125.7	0.28	33	2267.1	215.8
	High						
1	Existing	16.0	86.5	0.35	33	1560.6	83.9
	Bare soil	17.7	175.1	0.40	33	3158.5	217.2
2	Existing	38.8	143.5	0.84	39	2186.9	56.4
	Bare soil	24.5	196.8	0.53	39	2999.3	122.9
3	Existing	8.7	10.8	0.18	34	189.9	21.4
	Bare soil	21.4	177.9	0.44	34	3133.9	156.2
4	Existing	17.9	56.1	0.35	30	1104.7	11.7
	Bare soil	23.3	196.0	0.45	30	3861.6	174.5

Management Implications

Two burn severities were conducted to examine their effects on runoff and sediment production. Erosion plots were located away from skid trails and landings to examine only the effect of these burn severities on sediment production. Both fires were within Forest Service guidelines for conducting prescribed burns. A large difference in sediment production can be observed by comparing the two treatments. With some care in the burning prescription, sediment yields it can be reduced to a negligible amount. If land managers can meet their silvicultural objectives with the low-severity fire, such a practice will greatly reduce the amount of sediment leaving the site and will preserve the site quality. By burning with a low-severity fire, the residual forest floor provides excellent protection of the mineral soil from raindrop splash, overland flow detachment, and rill development. It also provides a large water holding capacity to help planted species survive.

These data are being used with other information to develop a physical process-oriented model of sediment production from timber harvest areas.

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